OPEN-FILE REPORT 98-05

SEISMIC HAZARD EVALUATION OF THE PASADENA 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

1998

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

DIVISION OF MINES AND GEOLOGY

JAMES F. DAVIS, *STATE GEOLOGIST*

OPEN-FILE REPORT 98-05

SEISMIC HAZARD EVALUATION OF THE PASADENA 7.5-MINUTE QUADRANGLE, LOS ANGELES COUNTY, CALIFORNIA

DIVISION OF MINES AND GEOLOGY'S PUBLICATION SALES OFFICES:

Southern California Regional Office
655 S. Hope Street, Suite 700
Los Angeles, CA 90017
(213) 239-0878

Publications and Information Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 445-5716

Bay Area Regional Office
185 Berry Street, Suite 210
San Francisco, CA 94107-1728
(415) 904-7707

CONTENTS

ILLUSTRATIONS

PREFACE

With the increasing public concern about the potential for destructive earthquakes in northern and southern California, the State Legislature passed the Seismic Hazards Mapping Act in 1990. The purpose of the Act is to protect the public from the effects of strong ground shaking, liquefaction, landslides or other ground failure, and other hazards caused by earthquakes. The program and actions mandated by the Seismic Hazards Mapping Act closely resemble those of the Alquist-Priolo Earthquake Fault Zoning Act (which addresses only surface fault-rupture hazards) and are outlined below:

1. **The State Geologist** is required to delineate the various "seismic hazard zones."

2. **Cities and Counties**, or other local permitting authorities, must regulate certain development "projects" within the zones. They must withhold the development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans.

3. **The State Mining and Geology Board (SMGB)** provides additional regulations, policies, and criteria to guide cities and counties in their implementation of the law. The SMGB also provides criteria for preparation of the Seismic Hazard Zone Maps (Web site http://www.consrv.ca.gov/dmg/shezp/zoneguid/) and for evaluating and mitigating seismic hazards.

4. **Sellers (and their agents)** of real property within a mapped hazard zone must disclose at the time of sale that the property lies within such a zone.

As stated above, the Act directs the State Geologist, through the Division of Mines and Geology (DMG) to delineate seismic hazard zones. Delineation of seismic hazard zones is conducted under criteria established by the Seismic Hazards Mapping Act Advisory Committee and its Working Groups and adopted by the California SMGB.

The Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Evaluation Reports, released as Open-File Reports (OFR), summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These Open-File Reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. Copies of the reports may be purchased at the Sacramento, Los Angeles, and San Francisco offices. In addition, the Sacramento office offers prepaid mail order sales for all DMG OFRs. **NOTE: The Open-File Reports are not available through BPS Reprographic Services.**

DIVISION OF MINES AND GEOLOGY OFFICES

Geologic Information and Publications Office
801 K Street, MS 14-33
Sacramento, CA 95814-3532
(916) 445-5716

Bay Area Regional Office
185 Berry Street, Suite 210
San Francisco, CA 94107-1728
(415) 904-7707

Southern California Regional Office
655 S. Hope Street, Suite 700
Los Angeles, CA 90017
(213) 239-0878

WORLD WIDE WEB ADDRESS

Seismic Hazard Evaluation Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet homepage:
http://www.consrv.ca.gov/dmg/shezp/

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that the 1) process for zoning liquefaction hazards remain unchanged and that 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Evaluation Report summarizes the development of the hazard zone map for each area. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historic high-water-table information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Pasadena 7.5-Minute Quadrangle (scale 1:24,000).

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Pasadena 7.5-Minute Quadrangle, Los Angeles County, California

By
Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Pasadena 7.5-minute Quadrangle (scale 1:24,000). This section and Section 2 addressing earthquake-induced landslides, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazards zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure has historically been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes, significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated granular sediments within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern California, most notably in some densely populated valley regions and alluviated floodplains. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in general, as well as in the Pasadena Quadrangle.

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils is generally confined to areas covered by Quaternary sedimentary deposits. Such areas consist mainly of alluviated valleys, floodplains, and canyon regions. The evaluation is based on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth data, most of which are gathered from a variety of sources. The quality of the data used varies. Although selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth and thickness of liquefiable sediments, depth to ground water, rate of drainage, slope gradient, proximity to free-face conditions, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to determine the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction potential, opportunity, susceptibility, and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Pasadena Quadrangle covers an area of about 62 square miles in central Los Angeles County. The southeastern quarter of the quadrangle contains the City of Pasadena, the Civic Center of which lies about 10 miles northeast of the Los Angeles Civic Center. The City of Glendale lies in the southwestern corner of the map area and is separated from Pasadena by the community of Eagle Rock, which is part of the City of Los Angeles. East-west access to these areas is by means of the Foothill Freeway (I-210) and Ventura Freeway (State Route 134). From the south, access is via the Glendale Freeway (State Route 2) or the Pasadena Freeway (State Route 110). North of the Verdugo Mountains and the San Rafael Hills, which lie within the west-central and central portions of the quadrangle, respectively, are the unincorporated Los Angeles County communities of La Crescenta, Verdugo City, and Montrose, as well as the City of La Canada Flintridge. These communities are arranged across the floor of the Tujunga Valley between the San Gabriel Mountains and the Verdugo Mountains. In the east-central part of the map area the unincorporated community of Altadena lies between the San Gabriel Mountains and the City of Pasadena. Approximately the northeastern third of the quadrangle is covered by the San Gabriel Mountains. The northern communities are accessible via the Foothill Freeway (I-210) or Foothill Boulevard.

The quadrangle includes the drainage divide between two of the major basins of southern California. The La Crescenta and Glendale areas are on the eastern edge of the San Fernando Valley. Pasadena is on the western edge of the San Gabriel Valley. The San Gabriel Mountains, which bound both valleys on the north, cover the northern portion of the Pasadena Quadrangle. The two major streams within quadrangle are the Verdugo Wash and the Arroyo Seco, which drain from north to south across the area. The Verdugo Wash drains from the north side of the Verdugo Mountains, where several tributaries from the San Gabriel Mountains join it, through the Verdugo Canyon between the Verdugo Mountains and the San Rafael Hills to the Glendale area, where it has deposited a major alluvial fan. The Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised a channel along the east side of the San Rafael Hills and the Eagle Rock and Highland Park area south to the Los Angeles River.

The valley portions of the Pasadena Quadrangle are covered with alluvial deposits of various ages. The La Crescenta and Altadena areas are built on recent alluvial fans from the San Gabriel Mountains. The central Glendale area is on the Verdugo Wash fan. Pasadena is largely on an older alluvial surface that is no longer active because of uplift and the incision of the Arroyo Seco through it. The Eagle Rock valley is an isolated valley within the uplift between the two major basins and has received sediment only from the surrounding hills.

GEOLOGIC CONDITIONS

Surface Geology

Late Quaternary geologic units (see Table 1.1 for list) in the Pasadena Quadrangle were compiled for this study from mapping by McCalpin (unpublished) and Smith (1986). McCalpin mapped the Quaternary geology of the San Gabriel Valley for the Southern California Areal Mapping Project (SCAMP). Smith (1986) mapped the bedrock geology and Quaternary geology of the northern half of the quadrangle. Crook and others (1987) also mapped the Quaternary geology of the northern part of the quadrangle, concentrating on the different alluvial units cut by the Sierra Madre and Raymond faults.

	Alluvial Fan Deposits	Alluvial Valley Deposits	Age
Active	Qf- active fan Qw- active wash	Qa- active depositional basin	
Young	Qyf2 Qyf1	Qya, Qya2 Qya1	Holocene
Old	Qof2 Qof1		Pleistocene
Very old	Qvof	Qvoa	

Some unit names include the “characteristic grain size” (e.g. Qyf2a, Qvofg)
b: boulder gravel, g: gravel, a: arenaceous (sand), s: silty, c: clayey.

Table 1.1. Units of the Southern California Areal Mapping Project (SCAMP) nomenclature used in the Pasadena Quadrangle.

In preparing the Quaternary geologic map for the Pasadena Quadrangle, geologic maps prepared by Lamar (1970), Crook and others (1987), Dibblee (1989), Smith (1986) and McCalpin (unpublished) were referred to. We began with the maps of McCalpin (unpublished) and Smith (1986) as files in the DMG Geographic Information System. These maps were in good agreement for most of the Quaternary units. McCalpin had completed his mapping more recently, primarily using soil surveys to determine the ages of various Quaternary geologic units. He also incorporated the mapping of Crook and others (1987), especially for areas of artificial fill, which McCalpin had not mapped originally (McCalpin, personal communication, 1998). McCalpin’s mapping also used the SCAMP nomenclature for geologic units (Morton and Kennedy, 1989). Smith mapped the bedrock geology of the north half of the quadrangle in detail, and also showed the geologic boundaries within the Quaternary units with more detail than McCalpin. The completed map of Quaternary geology primarily uses boundaries between the geologic units as mapped by Smith (1986) in the northern half and McCalpin in the southern half, with unit designations modified somewhat from McCalpin based on Crook and others (1987). The Quaternary geologic map of the Pasadena Quadrangle is reproduced as Plate 1.1.

The Quaternary geologic map (Plate 1.1) shows that the valley areas of the Pasadena Quadrangle are covered by alluvial fans of various ages, including remnants of very old fans along the front of the San Gabriel Mountains, older alluvial surfaces in Pasadena, and smaller fans from the San Gabriel Mountains to the north and west. The sources of the sediment that make up the young fans have been the small drainages, usually with only a few square miles of watershed, in the San Gabriel Mountains. The largest drainage in the area, the Arroyo Seco, has incised its channel through the Pasadena area to the Los Angeles River. Very little of the sediment from that drainage has been deposited in the incised channel. Sedimentation on the alluvial fans is primarily sand, silt, and gravel, the compositions of which reflects the crystalline rocks of the San Gabriel Mountains. On the Pasadena Quadrangle, the alluvial units have been subdivided into the Saugus Formation, very old alluvium, two generations of older alluvium (Qof1, Qof2), two generations of young alluvium (Qyf2, Qyf1) and active wash and fan deposits (Plate 1.1).

Subsurface Geology and Geotechnical Characteristics

The geologic units described above were mapped primarily from their surface expression, including descriptions of the soils from soil surveys used by McCalpin. This mapping was compared with the subsurface properties described in about 200 borehole logs in the study area. Subsurface data used for this study include the database compiled by John Tinsley for previous studies (Tinsley and Fumal, 1985; Tinsley and others, 1985), a database of shear wave velocity measurements originally compiled by Walter Silva (Wills and Silva, 1998), and additional data collected for this study. Subsurface data were collected for this study at Caltrans, the Los Angeles County Department of Public Works, CDMG files of seismic reports for hospital and school sites, the Regional Water Quality Control Board and from Law Crandall, Inc. In general, the data gathered for geotechnical studies appear to be complete and consistent. Data from environmental geology reports filed with the Water Quality Control Board is well distributed areally and provides reliable data on water levels. Geotechnical data, particularly SPT blow counts, from environmental studies are sometimes less reliable however, due to non-standard equipment and incomplete reporting of procedures

Data from previous databases and additional borehole logs were entered into the CDMG's "geotec" database, contained within the project GIS. Locations of all exploratory boreholes considered in this investigation are shown on Plate 1.2. Construction of cross sections from the borehole logs, using the GIS, enabled the correlation of soil types from one borehole to another and outlining of areas of similar soils.

Descriptions of characteristics of geologic units recorded on the borehole logs are given below. These descriptions are necessarily generalized but give the characteristics of the unit most commonly encountered.

Saugus Formation (Qs)

Saugus Formation was mapped in the Pasadena Quadrangle by Smith (1986). Crook and others (1987) and McCalpin (unpublished) map the same areas as parts of the oldest alluvial unit. Smith distinguished the Saugus Formation from overlying Pleistocene alluvium based on stratigraphic position, relative uplift, intensity of deformation and a distinctive suite of clasts, some of which are no longer present in the watersheds adjacent to the deposits.

Smith (1986) describes the Saugus Formation as a conglomeratic arkosic sandstone. Crook and others (1987) describe the same outcrops as part of their oldest alluvial unit, an unconsolidated to well consolidated fine to medium sand with gravel. No subsurface data were collected for this unit because it is described as a well-consolidated unit and is found in an area of deep ground water.

Very old alluvium (Qvoa, Qvof)

Very old alluvium is also mapped along the front of the San Gabriel Mountains. Locally, it extends as alluvial fans into the La Crescenta and La Canada areas. Crook and others (1987) describe these fans as red to reddish brown, or yellow unconsolidated to well consolidated fine to medium sand with gravel (the same as the unit Smith (1986) maps as Saugus Formation). Borehole logs by Caltrans in the very old alluvial fan (Qvof2) northeast of Montrose describe dense to very dense poorly sorted sand with thin interbeds of silty sand. No subsurface data were collected for most of this unit because it is a generally well-consolidated unit and is located in an area of deep ground water.

Older alluvium (Qof1, Qof2)

Older alluvium is mapped as remnants of small alluvial fans in the La Crescenta and La Canada areas and the surface that underlies most of the City of Pasadena. Unit Qof1 in Pasadena is composed of sand and silty sand with some layers of silt. In the La Crescenta area it is described as dense to very dense sandy gravel and gravelly sand. Unit Qof2 in northwest Pasadena is described as very dense gravelly sand and sandy gravel. In the La Canada area it is described as dense to very dense sand with some gravel.

Younger alluvium (Qyf1, Qyf2, Qf, Qw)

Alluvial fans from different drainages can be distinguished by their geomorphic expression and can have differing soil profiles due to different bedrock in their source areas. Within an alluvial fan, the different generations of younger alluvium can be distinguished by their geomorphic relationships. In the subsurface, it is not possible to distinguish among the generations on a young alluvial fan. There may simply be too little difference in age among these units, which probably range from mid-Holocene to historic, for any differences in density or cementation to have formed.

Fans from the San Gabriel Mountains

Young alluvial fans in the La Crescenta area are composed of sand and gravelly sand, generally described as compact to dense. In the La Canada area, young alluvial fans are composed of moderately dense to dense sand and silty sand.

Verdugo Wash and fan

Drainage from the San Gabriel Mountains into the La Crescenta area flows through the Verdugo Canyon to the central Glendale area, where a young alluvial fan has formed. Material deposited in the canyon and on the fan is similar to the fans upstream in the La Crescenta area. In the Verdugo Canyon deposits are described as gravelly sand, silty sand and sandy gravel, and are loose to dense. The Verdugo wash fan in Glendale is composed of similar loose to dense gravelly sand, silty sand, and sandy gravel

Arroyo Seco

The Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised its drainage through the Pasadena Quadrangle. Deposits of the Arroyo Seco are found only within the incised canyon. These deposits are described on borehole logs as silty sand and gravelly silty sand. We were not able to acquire borehole logs with the results of SPT tests. The consistency of this material is not well known.

Young alluvium of the Eagle Rock area (Qya1, Qya2)

The Eagle Rock Valley lies within the uplifted area between the Verdugo Wash and the Arroyo Seco. It is surrounded by low hills composed mostly of Topanga Formation sandstone and conglomerate. The alluvium in this valley is composed of silty and clayey sand with interbedded clay. The granular deposits are very loose to medium dense with SPT blow counts as low as 1.

Artificial fill (af)

Artificial fill in the Pasadena Quadrangle consists of engineered fill for freeways and other developments and waste landfills. Engineered fills are generally too thin to have an affect on liquefaction hazard and so were not investigated. The waste landfills are within the San Rafael Hills, where ground water is generally deep.

GROUND-WATER CONDITIONS

The Pasadena Quadrangle lies on the drainage divide between two major basins. The San Fernando Valley lies to the west and the San Gabriel Valley is on the east. Both are important sources of ground water. The San Fernando Valley ground-water basin was the subject of a lawsuit by the City of Los Angeles against the City of San Fernando and other operators of water wells in the basin. The "Report of Referee" (California State Water Rights Board, 1962) contains information on the geology, soils and ground-water levels of the San Fernando Valley, including the Glendale area, the La Crescenta area, and the Verdugo Canyon. Mendenhall (1908) studied the San Gabriel Valley's ground-water resources before pumping for agriculture and domestic use caused a decline in ground-water levels.

The Report of Referee shows that ground water in the San Fernando Valley reached its highest levels in 1944, before excessive pumping caused drawdowns throughout the basin. Management of the ground-water resources led to stabilizing of ground-water elevations in the 1960's and, in some cases, rise of ground-water elevations in the 1970's and 1980's to levels approaching those of 1944 (Blevins, 1995).

In order to consider the historically highest ground-water level in liquefaction analyses, the 1944 ground-water elevation contours (State Water Rights Board 1962, Plate 29) and the ground-water elevation contours of Mendenhall (1908) were digitized. A three-dimensional model was created from the digitized contours giving ground-water elevation at any point on a grid. The ground-water elevation values in this grid were then subtracted from the surface elevation values from the USGS Digital Elevation Model (DEM) for the Pasadena Quadrangle. The difference between the surface elevation and the ground-water elevation is the ground-water depth. Subtracting the ground-water elevation grid from the DEM results in a grid of ground-water depth values at any point where the grids overlapped.

The resulting grid of ground-water depth values shows several artifacts of the differences between the sources of ground-water elevation data and surface elevation data. The ground-water elevations were interpreted from relatively few measurements in water wells. The USGS DEM is a much more detailed depiction of surface elevation; it also shows man-made features such as excavations or fills that have changed the surface elevations. Most of these surface changes occurred after the historic ground-water levels were measured. The ground-water depth contours were smoothed and obvious artifacts removed to create the final ground-water depth map (Plate 1.2).

The historic ground-water depths were checked against the water levels measured in boreholes compiled for this study. Measured ground-water levels from the 1970's, 1980's and early 1990's tend to be 10 to 20 feet deeper than the historic water level, but show a similar pattern of deep and shallow ground-water areas. The final map of depth to ground water (Plate 1.2) reflects the historic water levels over most of the quadrangle with minor adjustments to reflect detailed information gathered for this study.

The Eagle Rock Valley is somewhat isolated from the two major basins and was not studied in the same level of detail. Ground-water levels in wells in the Eagle Rock area are within 10 to 20 feet of the surface based on measurements recorded on borehole logs collected for this study. Several borehole logs along Eagle Rock Boulevard near the southern boundary of the quadrangle show saturated granular sediments overlying a clay layer and granular sediments under the clay layer that do not appear to be saturated. This suggests a local water table perched on the clay layer, which may not be related to deeper aquifers.

Ground water is also relatively shallow in all canyons in the San Gabriel Mountains where records were examined. In general, it appears that relatively shallow and impermeable bedrock underlying the canyon alluvium helps to maintain a shallow water table.

PART II

EVALUATING LIQUEFACTION POTENTIAL

Liquefaction occurs in water saturated sediments during moderate to great earthquakes. Liquefied sediments are characterized by a loss of strength and may fail, causing damage to buildings, bridges, and other such structures. A number of methods for mapping liquefaction hazard have been proposed; Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of susceptibility units, and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to evaluate liquefaction potential. Liquefaction susceptibility is a function of the capacity of sediments to resist liquefaction and liquefaction opportunity is a function of the seismic ground shaking intensity. The application of the Seed Simplified Procedure (Seed and Idriss, 1971) for evaluating liquefaction potential allows a quantitative characterization of susceptibility of geologic units. Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for mapping liquefaction hazards in the Los Angeles region. The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985), combining geotechnical data analyses, and geologic and hydrologic mapping, but follows criteria adopted by the California State Mining and Geology Board (in press).

LIQUEFACTION OPPORTUNITY

According to the criteria adopted by the California State Mining and Geology Board (in press), liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for ground shaking strong enough to generate liquefaction. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period. The earthquake magnitude is the magnitude that contributes most to the acceleration.

For the Pasadena Quadrangle, peak accelerations of 0.53 g to 0.82 g, resulting from a predominant earthquake of magnitude 6.4 to 7.0 were used for liquefaction analyses. The PGA and magnitude values were derived from maps prepared by Petersen and others (1996) and

Cramer and Petersen (1996), respectively. See the ground motion portion (Section 3) of this report for further details.

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of soils to loss of strength when subjected to ground shaking. Primarily, physical properties and conditions of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance. Soils that lack resistance (susceptible soils) are typically saturated, loose sandy sediments. Soils resistant to liquefaction include all soil types that are dry or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil-property and soil-condition factors such as type, age, texture, color, and consistency, along with historic depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, findings can be related to the map units. A qualitative susceptible soil inventory is outlined below and summarized in Table 1.2.

Geologic Map Unit	Material Type	Consistency	Liquefaction Susceptibility
Qw, stream channels	Sandy gravel, gravelly sand	Loose- dense	high
Qf, active alluvial fans	Sand, gravelly sand,	Loose-moderately dense	high
Qyf2, Qyf1 young alluvial fans	Sand, gravelly sand,	Loose-moderately dense	high
Qya2, Qya1, young alluvial valley deposits	Silty sand, clay, clayey sand	Loose-moderately dense	high
Qof1, older alluvial fan	Sand & gravel	Dense-very dense	low
Qof2, older alluvial fan	Sand & gravel	Dense-very dense	low
Qvoa, very old alluvium	Sand & gravel	Dense-very dense	low
Qvof, very old alluvial fan	Sand & gravel	Dense-very dense	low

Table 1.2. General geotechnical characteristics and liquefaction susceptibility of younger Quaternary units.

Very old alluvium (Qvof)

Very old alluvium on the Pasadena Quadrangle is dense to very dense and is found in areas of deep ground water. Its susceptibility to liquefaction is low.

Old alluvium (Qof1, Qof2)

Old alluvium on the Pasadena Quadrangle is dense to very dense and is found in areas of deep ground water. Its susceptibility to liquefaction is low.

Young alluvial fans and channel deposits (Qyf1, Qyf2, Qf, Qw)

Younger alluvium on the Pasadena Quadrangle consists of sand, gravelly sand, and silty sand. Most boreholes in these units contain loose to moderately dense sand. Some contain very loose sand. Where ground water is within 40 feet of the surface liquefaction susceptibility of these units is high.

Young alluvial valley deposits (Qya, Qya1, Qya2)

Young alluvial valley deposits in the Eagle Rock area consist of sandy clay, clay, and layers of sand. Sand layers are loose to moderately dense and ground water (possibly a perched zone) is high. Susceptibility to liquefaction is considered high.

Artificial fill (af)

Artificial fill on the Pasadena Quadrangle consists of engineered fill for freeways and waste landfills. The engineered fill is generally too thin to affect liquefaction susceptibility. The waste landfills are located in the San Rafael Hills, an area of deep ground water. They have low liquefaction susceptibility due to the deep ground water.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; Seed and Harder, 1990; Youd and Idriss, 1997). This procedure calculates soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR) based on standard penetration test (SPT) results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses, expressed in terms of cyclic stress ratio (CSR). The factor of safety (FS) relative to liquefaction is: FS=CRR/CSR. FS, therefore, is a quantitative measure of liquefaction potential. Generally, a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, indicates the presence of potentially liquefiable soil. DMG uses FS, as well as other considerations such as slope, free face conditions, and thickness and depth of potentially liquefiable soil, to construct liquefaction potential maps, which then directly translate to Zones of Required Investigation.

Of the 200 borehole logs compiled for this study, only about 120 include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 1/2-inch inside diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. Few borehole logs, however, include all of the information (soil density, moisture content, sieve analysis, etc.) required for an ideal Seed Simplified Analysis. For boreholes having acceptable penetration tests, liquefaction analysis is performed using logged density, moisture, and sieve test values, or using average test values of similar materials from Standard Penetration Tests or from tests that could be converted to SPT's. Few included all of the required information (SPTs, density, water content, percentage of silt and clay size grains) for a complete Seed Simplified Analysis. For those boreholes where SPTs were recorded, the liquefaction analysis was conducted using data extrapolated from other boreholes nearby or in similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

The areas underlain by late Quaternary geologic units were included in liquefaction zones using the criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (in press). Under those criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historic earthquakes.

2. All areas of uncompacted fills containing liquefaction susceptible material that are saturated, nearly saturated, or may be expected to become saturated.

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable.

4. Areas where existing geotechnical data are insufficient**.**

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historic high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historic high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria for liquefaction zoning in the Pasadena Quadrangle is summarized below.

Areas of Past Liquefaction

In the Pasadena Quadrangle, no areas of documented historic liquefaction are known. Areas showing evidence of paleoseismic liquefaction have not been reported.

Artificial Fills

In the Pasadena Quadrangle, two kinds of artificial fill are large enough to show at the scale of mapping, engineered fill for freeways, and waste landfills. The engineered fills are generally too thin to have an impact on liquefaction hazard and so were not investigated.

Areas with Existing Geotechnical Data

Younger alluvial deposits (Qyf1, Qyf2, Qw) in the Pasadena Quadrangle fan have generally high liquefaction susceptibility. All younger alluvium where ground water has been less than 40 feet from the surface are included in a liquefaction zone.

Areas without Existing Geotechnical Data

We were not able to collect borehole logs from the alluvial channel deposits of the Arroyo Seco that recorded results of SPT tests. Consequently, we were not able to quantitatively analyze the liquefaction susceptibility of these deposits. Based on the shallow water table and young age of the deposits, they meet the criteria for zoning of the State Mining and Geology Board (in press).

ACKNOWLEDGMENTS

The authors would like to thank the staff at the California Department of Transportation (CalTrans), and the Los Angeles Regional Water Quality Control Board for their assistance in the collection of subsurface borehole data. Marshall Lew of Law-Crandall, Inc. generously provided access to pertinent report files at his firm. At DMG, special thanks to Bob Moskovitz, Teri McGuire, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for designing and plotting the graphic displays associated with the liquefaction zone map and this report.

REFERENCES

Blevins, M. L., 1995, Watermaster Service in the Upper Los Angeles River Area, Los Angeles County, 1993-1994 water year: Upper Los Angeles River Area Watermaster, 45 p.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

California State Water Rights Board, 1962, Report of Referee, in the Superior Court of the State of California in and for the County of Los Angeles, The City of Los Angeles, a Municipal Corporation, Plaintiff, vs. City of San Fernando, a Municipal Corporation, *et al*, Defendants, No. 650079, volume 1, 258 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.

Crook, R. Jr., Allen, C.R., Kamb, B., Payne, C.M. and Proctor, R.J., 1987, Quaternary Geology and seismic hazard of the Sierra Madre and associated faults, western San Gabriel Mountains, *in* Recent reverse faulting in the Transverse Ranges, California: U.S. Geological Survey Professional Paper 1339, p. 7 –26.

Dibblee, T.W., Jr., 1989, Geologic map of the Pasadena Quadrangle, Los Angeles County, California: Dibblee Geological Foundation Map DF-23, Santa Barbara, California, scale 1:24,000.

Lamar, D.L., 1970, Geology of the Elysian Park- Repetto Hills area, Los Angeles County, California: California Division of Mines and Geology Special Report 101, 45 p.

McCalpin, J.P., unpublished, Digital geologic map of the Pasadena 7.5-minute Quadrangle, Los Angeles County, California: contracted for the Southern California Areal Mapping Project (SCAMP), resolution 1:24000.

Mendenhall, W.C., 1908, Ground waters and irrigation enterprises of the foothill belt, southern California: U.S. Geological Survey Water Supply Paper 219, 180 p.

Morton, D. M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series: The Santa Ana Quadrangle, The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

Petersen, M.D., Cramer, C.H., Bryant, W. A., Reichle, M. S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, affected by the 17 January 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Seed, H.B. and Idriss, I. M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.

Seed, H.B., Idriss, I. M., and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.

Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.

Smith, D. P., 1986, Geology of the north half of the Pasadena Quadrangle, Los Angeles County, California: Division of Mines and Geology Open File Report 86-4 LA, 40 p.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Tinsley, J.C. and Fumal, T.E., 1985, Mapping Quaternary sedimentary deposits for areal variations in shaking response, *in* Ziony, J. I., *editor*, Evaluating earthquake hazards in the Los Angeles Region - An earth-science perspective: U.S. Geological Survey Professional Paper 1360, p. 101 - 125.

Tinsley, J.C., Youd, T. L., Perkins, D. M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I. *editor*, Evaluating earthquake hazards in the Los Angeles region -- an earth science perspective: U.S. Geological Survey Professional Paper 1360, p 263-316.

Wills, C. J. and W. Silva, 1998, Shear wave velocity characteristics of geologic units in California: Earthquake Spectra, v. 14, p. 533-556.

Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.

Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.

Youd, T.L. and Perkins, D.M. 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.

SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Pasadena 7.5-Minute Quadrangle, Los Angeles County, California

By

Rick I. Wilson and Christopher J. Wills

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/pubs/sp/117/).

This evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Pasadena 7.5-minute Quadrangle (scale 1:24,000). This section and Section 1 addressing liquefaction, are part of a series that will summarize development of similar hazard zone maps in the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

BACKGROUND

Landslides triggered by earthquakes have historically been a major cause of earthquake damage. Landslides triggered by the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes were responsible for destroying or damaging numerous homes and other structures, blocking major transportation corridors, and damaging various types of life-line infrastructure. Typically, areas most susceptible to earthquake-induced landslides are steep slopes and on or adjacent to existing landslide deposits, especially if the earth materials in these areas are composed of loose colluvial soils, or poorly cemented or highly fractured rock. These geologic and terrain conditions exist in many parts of southern California, most notably in hilly areas already developed or currently undergoing development. In addition, the opportunity for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region, which includes the Pasadena Quadrangle.

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered primarily from a variety of outside sources; thus the quality of the data is variable. Although the selection of data used in this evaluation was rigorous, the state of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Earthquake-generated ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. No attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Pasadena Quadrangle, for more information on the delineation of Liquefaction Zones.

Information developed in the study is presented in two parts: physiographic, and geologic conditions in PART I, and ground shaking opportunity, landslide hazard potential and zoning evaluations in PART II.

PART I

STUDY AREA LOCATION AND PHYSIOGRAPHY

The Pasadena Quadrangle covers an area of about 62 square miles in central Los Angeles County. The southeastern quarter of the quadrangle contains the City of Pasadena, the Civic Center of which lies about 10 miles northeast of the Los Angeles Civic Center. The City of Glendale lies in the southwestern corner of the map area and is separated from Pasadena by the community of Eagle Rock, which is part of the City of Los Angeles. East-west access to these areas is by means of the Foothill Freeway (I-210) and Ventura Freeway (State Route 134). From the south, access is via the Glendale Freeway (State Route 2) or the Pasadena Freeway (State Route 110). North of the Verdugo Mountains and the San Rafael Hills, which lie within the west-central and central portions of the quadrangle, respectively, are the unincorporated Los Angeles County communities of La Crescenta, Verdugo City, and Montrose, as well as the City of La Canada Flintridge. These communities are arranged across the floor of the Tujunga Valley between the San Gabriel Mountains and the Verdugo Mountains. In the east-central part of the map area the unincorporated community of Altadena lies between the San Gabriel Mountains and the City of Pasadena. Approximately the northeasten third of the quadrangle is covered by the San Gabriel Mountains. The northern communities are accessible via the Foothill Freeway (I-210) or Foothill Boulevard.

The quadrangle includes the drainage divide between two of the major basins of southern California. The Glendale area lies on the eastern edge of the San Fernando Valley and La Crescenta lies within the Tujunga Valley, which is a tongue of the San Fernando Valley. Altadena, Pasadena, and La Canada Flintridge are on the western edge of the San Gabriel Valley. The San Gabriel Mountains bound both valleys on the north. The San Gabriel Mountains are composed of plutonic rocks of Precambrian through Cretaceous age that have been thrust to the south over the adjacent basins. The Verdugo Mountains and the San Rafael Hills are also composed of crystalline rocks similar to those of the San Gabriel Mountains. South of the Eagle Rock fault, which bounds the San Rafael Hills north of the Ventura Freeway, the hills are composed of sandstone and conglomerate of the Topanga Formation, with some areas of plutonic rock.

The two major stream courses within quadrangle are Verdugo Wash and Arroyo Seco, both of which drain from north to south across the area. Verdugo Wash drains from the north side of the Verdugo Mountains, where several tributaries from the San Gabriel Mountains join it, through Verdugo Canyon between the Verdugo Mountains and the San Rafael Hills to the Glendale area, where it has deposited a major alluvial fan. Arroyo Seco has cut a major canyon in the San Gabriel Mountains and incised a channel along the east side of the San Rafael Hills and the Eagle Rock and Highland Park area south to the Los Angeles River.

The valley portions of the Pasadena Quadrangle are covered with alluvial deposits of various ages. The La Crescenta and Altadena areas are built on recent alluvial fans from the San Gabriel

Mountains. The central Glendale area is on the Verdugo Wash fan. Pasadena is largely on an older alluvial surface that is no longer active because of uplift and the incision of the Arroyo Seco through it. The Eagle Rock valley is an isolated valley within the uplift between the two major basins and has received sediment only from the surrounding hills. For details of the properties of the Quaternary geologic units see Section 1.

Residential and commercial development is concentrated in the valley areas. Hillside residential development began before World War II with small developments of single homes or cabins along streams at the base of the San Gabriel Mountains. Hillside development continues today with small residential developments in the Verdugo Mountains and San Rafael Hills.

GEOLOGIC CONDITIONS

Surface and Bedrock Geology

Recently compiled geologic maps were obtained in digital form from the Southern California Areal Mapping Project (Morton and Kennedy, 1989). These maps included the Quaternary geologic map of McCalpin (unpublished) for the Pasadena Quadrangle and the geologic map of the north half of the Pasadena quadrangle by Smith (1986). The maps were compared with other geologic maps of the area by Lamar (1970), Dibblee (1989), and Crook and others (1987). The mapping was briefly field checked. Observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to development and abundance of landslides was noted.

The San Gabriel Mountains in the northern part of the quadrangle, and their southern outliers the Verdugo Mountains and San Rafael Hills, are blocks of plutonic igneous and metamorphic rocks that are being thrust over the adjacent valleys from the north.

Bedrock geology in the crystalline bedrock of the Verdugo and San Gabriel Mountains shown by McCalpin (unpublished) is simplified to just one unit called Mx (Mesozoic crystalline rocks). Smith (1986) mapped the bedrock geology of the northern part of the quadrangle in great detail, and also shows the locations of contacts between crystalline rocks and Quaternary sediments with more detail than McCalpin. In order to show as much detail in the bedrock as feasible, and show contacts as accurately as possible, the completed geologic map for this evaluation uses primarily the boundaries between the geologic units as mapped by Smith (1986) in the northern half, and those mapped by McCalpin in the southern half, with unit designations from Smith (1986) for the bedrock units.

Major crystalline bedrock units mapped by Smith (1986) in the Pasadena Quadrangle include gneissic rocks mapped as augen gneiss (ag), metamorphic-granitic complex (mg; lgm), alaskite (ga), and metasedimentary rocks (ms; mp). These have been intruded by dioritic igneous rocks mapped as biotite-hornblende diorite (bhd), hornblende diorite (hd; hdw), hornblende-biotite diorite (hbd), biotite-quartz diorite (bqd), monzonite (ml), cataclastic quartz monzonite (qmc), and coarse-grained hornblende diorite (hdr). Smaller intrusions of granitic rocks, including granite (ge), leucocratic granodiorite (gl), and granitic complex (gc), and zones of cataclastic rocks (cc), also occur.

South of the Eagle Rock Fault, in the southern San Rafael Hills, Miocene Topanga Formation (Tt) of probable marine origin (Lamar, 1970) is exposed in a number of low-lying hills. The Topanga Formation consists of primarily crudely bedded conglomerate with sandstone and, to a lesser extent, silty shale interbeds.

Late Tertiary (?) to Quaternary sedimentary rocks exist within the southern flank of the San Gabriel Mountains. The Saugus and Pacoima formations (Qs and Qp, respectively), both mapped by Smith (1986), consist of conglomeratic arkosic sandstone of stream channel, flood plain, and alluvial fan origin.

Other surficial units in the mountainous areas include older alluvial fan deposits (Qof, Qoa), colluvium (Qc, Qco), talus (Qta, Qto), slopewash (Qsw, Qswo), and sand and gravel in the active stream channel (Qw, Qwg). Elevated terraces of young alluvium (Qyf) and older alluvium (Qoa) are present locally along the canyon edges above the modern channel level. In some areas of mass grading and residential development, artificial fill (af) has been mapped in and around the mountainous areas.

The valley areas of the Pasadena Quadrangle are covered by alluvial deposits derived from the San Gabriel Mountains and Verdugo Hills. These deposits include remnants of very old fans (Qvoa), older alluvial surfaces (Qoa, Qof), and coalescing younger fans (Qyf). A more detailed discussion of the Quaternary deposits in the Pasadena Quadrangle can be found in Section 1.

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, they must first be ranked on the basis of their overall shear strength. The primary source for rock shear-strength measurements for the Pasadena Quadrangle are geotechnical reports prepared by consultants, on file with: 1) the Los Angeles County Public Works Department, 2) City of Los Angeles, Department of Public Works, and 3) the City of Glendale, Public Works Division. Geotechnical and engineering geologic reports contained in Environmental Impact Reports and Hospital Review Project files at DMG are additional sources. Where shear strength information was lacking for certain rock units within the Pasadena Quadrangle itself, it was collected from adjacent areas. The locations of rock and soil samples taken for shear testing are shown on Plate 2.1.

Shear strength data gathered from the above source were compiled for the dominant rock types within the quadrangle and subdivided for fine-grained and coarse-grained lithologies if appropriate. Geologic units were grouped on the basis of the average angle of internal friction (average f) and lithologic character. Geologic formations that had little or no shear test information were added to existing groups on the basis of lithologic and stratigraphic similarities.

To subdivide mapped geologic formations that have both fine-grained and coarse-grained lithologies, we assumed that where stratigraphic bedding dips into a slope (favorable bedding) the coarse-grained material strength dominates, and where bedding dips out of a slope (adverse bedding) the fine-grained material strength dominates. We then used structural information from the geologic map (see "Structural Geology") and terrain data in the form of slope gradient and aspect, to identify areas with a high potential for containing adverse bedding conditions. These areas, located on the map, were then used to modify the geologic material-strength map to reflect the anticipated lower shear strength for the fine-grained materials.

The results of the grouping of geologic materials in the Pasadena Quadrangle are in Tables 2.1 and 2.2.

Structural Geology

Accompanying the digital geologic map (Smith, 1986) were digital files of associated geologic structural data, including bedding and foliation attitudes (strike and dip) and fold axes. We used the structural geologic information provided with the digital geologic map (Smith, 1986) and from Dibblee (1989) to categorize areas of common stratigraphic dip direction and magnitude,

PASADENA QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number of Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	grantic dioritic granodioritic gneissic	35 14 7 1	37/37 37/36 44/42 35/35	38/37	557/500	cc	38
GROUP 2	Tt(fbc)	52	34/35	34/35	487/338		34
GROUP 3	Qoa Qof Qyf Qw Qc af	29 6 11 10 3 40	32/30 29/29 30/30 32/31 28/28 31/31	31/30	285/250	Qs, Qp Qvoa Qta,Qto Qya Qsw, Qswo Qwg	31
GROUP 4	Tt(abc)	12	26/28	26/28	494/425		26
GROUP 5	Qls	22	15/16	15/16	440/315		15

* Generic rock types identified in this column can be linked to more-specific rock types discussed in the Surface and Bedrock Geology section.

abc=adverse bedding condition, fine-grained material strength

fbc=favorable bedding condition, coarse-grained material strength

Table 2.1. Summary of the shear strength statistics for the Pasadena Quadrangle.

SHEAR STRENGTH GROUPS FOR THE PASADENA QUADRANGLE				
GROUP 1	**GROUP 2**	**GROUP 3**	**GROUP 4**	**GROUP 5**
Ga mp bhd hbd bqd gc hd lgm gl ag mg ms hdr ge qmc hdw ml cc	Tt(fbc)	Qs qp Qvoa Qc Qco Qsw Qswo Qto Qta Qw Qwg Qya Qyf af	Tt(abc)	Qls

Table 2.2. Summary of the shear strength groups for the Pasadena Quadrangle.

similar to the method presented by Brabb (1983). The dip direction category was compared to the slope aspect (direction) category and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude category was less than or equal to the slope gradient category, and the bedding dip was greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area. This information was then used to subdivide mapped geologic units into areas where fine-grained and coarse-grained strengths would be used.

Landslide Inventory

The evaluation of earthquake-induced landsliding requires an up-to-date and complete picture of the previous occurrence of landsliding. An inventory of existing landslides in the Pasadena Quadrangle was prepared (Treiman, unpublished) by combining field observations, analysis of aerial photos, and interpretation of landforms on current and older topographic maps. Aerial photos taken the U.S. Department of Agriculture (1952/53) were the primary source for landslide interpretation. Also consulted during the mapping process were previous maps and reports that contain geologic and landslide data (Dibblee, 1989; Smith, 1986; Morton and Streitz, 1969; Crook and others, 1987). The completed hand-drawn landslide map was scanned and digitized by the Southern California Areal Mapping Project (SCAMP) at U.C. Riverside. A landslide database was attributed with information on confidence of interpretation (definite, probable, or questionable) and other properties, such as activity, thickness, and associated geologic unit(s). All landslides on the digital geologic map (from Smith, 1986) were verified or re-mapped during preparation of the inventory map. To keep the landslide inventory of consistent quality, all landslides originally depicted on the digitized geologic map were deleted, and only those included in the DMG inventory were incorporated into the hazard-evaluation process. A version of this landslide inventory is included with Plate 2.1.

PART II

EARTHQUAKE-INDUCED LANDSLIDE GROUND SHAKING OPPORTUNITY

Design Strong-Motion Record

The Newmark analysis used in delineating the earthquake-induced landslide zones requires the selection of a design earthquake strong-motion record. For the Pasadena Quadrangle, the selection was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996; Cramer and Petersen, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.7 to 7.0
Modal Distance:	2.5 to 7.4 km
PGA:	0.60 to 0.83g

The strong-motion record selected was the Channel 3 (north horizontal component) University of Southern California Station #14 recording from the magnitude 6.7 Northridge earthquake (Trifunac and others, 1994). This record had a source to recording site distance of 8.5 km and a PGA of 0.69g. The selected strong-motion record was not scaled or otherwise modified prior to analysis.

Displacement Calculation

To develop a relationship between the yield acceleration (a_y; defined as the horizontal ground acceleration required to cause the factor of safety to equal 1.0) and Newmark displacements, the design strong-motion record was integrated twice for a given a_y to find the corresponding displacement, and the process repeated for a range of a_y (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for any combination of geologic material strength and slope angle, as represented by the yield acceleration. We used displacements of 30, 15 and 5 cm as criteria for rating levels of earthquake shaking damage on the basis of the work of Youd (1980), Wilson and Keefer (1983), and the DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.076, 0.13 and 0.23 g. Because these yield acceleration values are derived from the design strong-motion

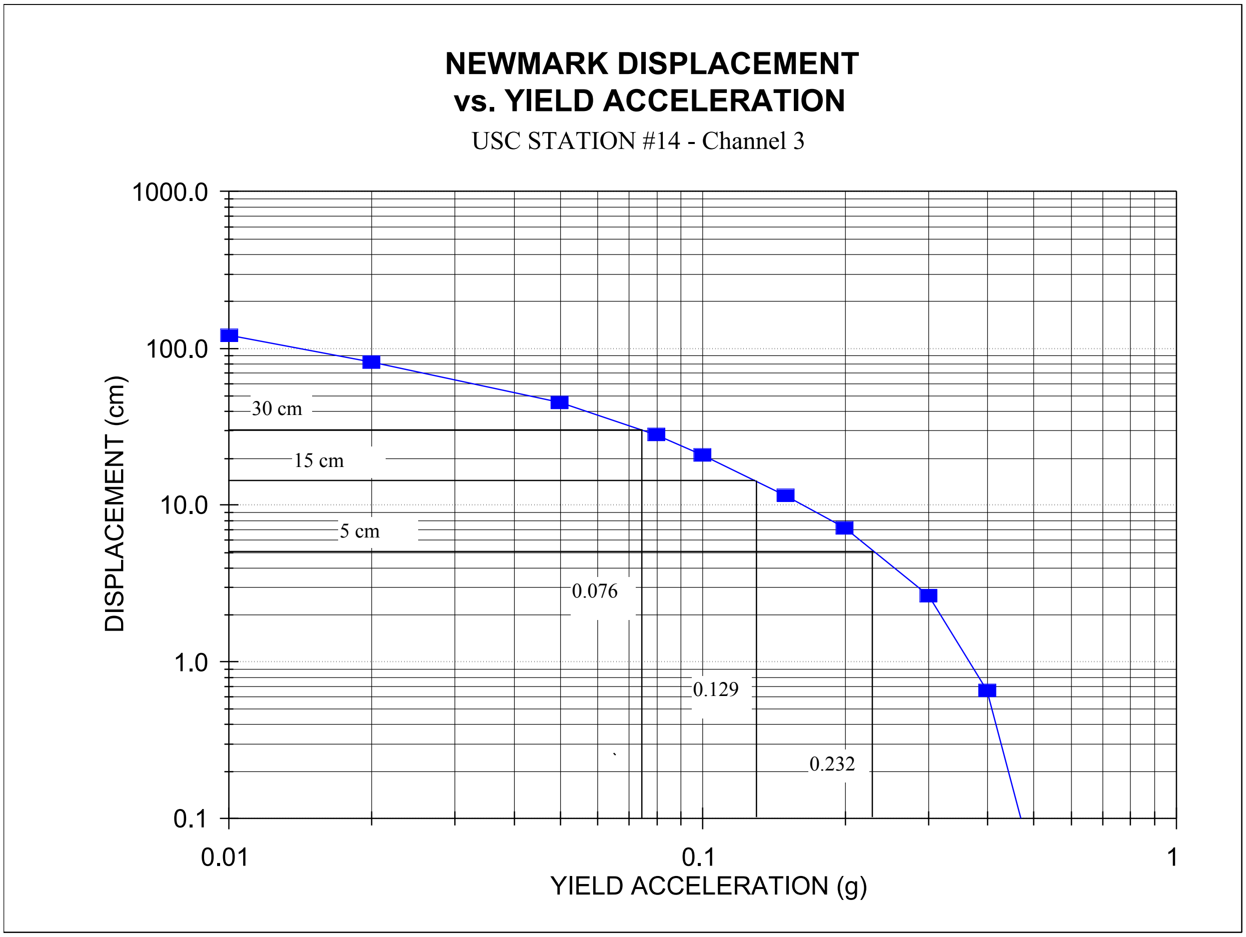


Figure 2.1. Yield acceleration vs. Newmark displacement for the USC Station #14 strong-motion record from the 17 January 1994 Northridge, California Earthquake.

record, they represent the ground shaking opportunity thresholds that are significant to the Pasadena Quadrangle.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. To calculate slope gradient for the terrain within the Pasadena Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle contours, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy. Surrounding quadrangle DEMs were merged with the Pasadena DEM to avoid the loss of data at the quadrangle edges when the slope calculations were performed. A peak and pit smoothing process was then performed to remove errors in the elevation points.

To update the topographic base map, areas that have undergone large-scale grading as a part of residential development in the hilly portions of the Pasadena Quadrangle were identified on a separate map (see Palte 2.1). Terrain data for these areas were obtained from an airborne interferometric radar (TOPSAR) DEM flown and processed in August 1994 by NASA's Jet Propulsion Laboratory (JPL), and reprocessed by Calgis, Inc. (GeoSAR Consortium, 1995 and 1996). These terrain data were also smoothed prior to analysis.

Slope-gradient and aspect maps were made from the DEMs using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The slope-gradient maps were used first in conjunction with the aspect maps and geologic structural data to identify areas of potential adverse bedding conditions, and then again with the geologic strength map in preparation of the earthquake-induced landslide hazard potential map.

Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield acceleration calculated by Newmark's equations represents the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. The acceleration values were compared with the ground shaking opportunity, defined by Figure 2.1, to determine the earthquake-induced landslide hazard potential. Based on the criteria described in Figure 2.1 above, if the calculated yield acceleration was less than 0.076g, expected displacements could be greater than 30cm, and a HIGH (H on Table 2.3) hazard potential was assigned. Likewise, if the calculated a_y fell between 0.076 and 0.13g a

MODERATE (M on Table 2.3) hazard potential was assigned, between 0.13 and 0.23g a LOW (L on Table 2.3) potential was assigned, and if a_y were greater than 0.23g a VERY LOW (VL on Table 2.3) potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

PASADENA QUADRANGLE HAZARD POTENTIAL MATRIX										
		SLOPE CATEGORY								
Geologic Material Group	Mean Phi	I 0-13%	II 14-19%	III 20-24%	IV 25-35%	V 36-41%	VI 42-52%	VII 53-64%	VIII 65-69%	IX >70%
1	38	VL	VL	VL	VL	VL	VL	L	M	H
2	34	VL	VL	VL	VL	VL	L	M	H	H
3	31	VL	VL	VL	VL	L	M	H	H	H
4	26	VL	VL	VL	L	M	H	H	H	H
5	15	L	M	H	H	H	H	H	H	H

Table 2.3. Hazard potential matrix for earthquake-induced landslides in the Pasadena Quadrangle. Shaded area indicates hazard potential levels included within the hazard zone.

EARTHQUAKE-INDUCED LANDSLIDE ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (in press). Under those criteria, earthquake-induced landslide zones are areas meeting one or more of the following:

1. Areas known to have experienced earthquake-induced slope failure during historic earthquakes.

2. Areas identified as having past landslide movement, including both landslide deposits and source areas.

3. Areas where CDMG's analyses of geologic and geotechnical data indicate that the geologic materials are susceptible to earthquake-induced slope failure.

Existing Landslides

Studies of the types of landslides caused by earthquakes (Keefer, 1984) show that re-activation of the whole mass of deep-seated landslide deposits is rare. However, it has been observed that the steep scarps and toe areas of existing landslides, which formed as a result of previous landslide movement, are particularly susceptible to earthquake-induced slope failure. In addition, because they have been disrupted during landslide movement, landslide deposits are inferred to be weaker than coherent, undisturbed, adjacent source rocks. Finally, we felt that a long duration, San Andreas fault-type earthquake could be capable of initiating renewed movement in existing deep-seated landslide deposits. Therefore, all existing landslides identified in the inventory with a definite or probable confidence of interpretation were included in the hazard zone.

Earthquake-triggered landslides, primarily rockfalls, were observed in numerous places within the Pasadena Quadrangle resulting from the 5.8 ML Sierra Madre earthquake of June 28, 1991 (Barrows and Irvine, 1991). Beginning at about the 2,000-foot level in the Wilson Diorite, rockfalls were common along the Angeles Crest Highway. Although rock falls from very steep, cracked, and shattered basement-rock roadcut exposures were abundant, they were neither large enough or numerous enough to cause closure of the highway.

The 1994 Northridge earthquake caused a number of relatively small, shallow slope failures in the Pasadena Quadrangle (Harp and Jibson, 1995). Landslides attributed to the Northridge earthquake covered approximately 2 acres of land in the western half of the quadrangle, which is less than 1/2 of 1 percent of the total area covered by the map. Of the area covered by these Northridge earthquake landslides, 77% falls within the area of the hazard zone based on a computer comparison of the zone map and the Harp and Jibson (1995) inventory.

Geologic and Geotechnical Analysis

On the basis of a DMG pilot study (McCrink and Real, 1996) the earthquake-induced landslide zone includes all areas determined to lie within the High, Moderate and Low levels of hazard potential. Therefore, as shown in Table 2.3, geologic strength group 5 [E] is always included in the zone (mapped landslides): strength group 4 [D] materials are included in the zone for all slope gradients above 24%; strength group 3 [C] above 35%; strength group 2 [B] above 41%; and strength group 1 materials, the strongest rock types, are zoned for slope gradients above 52%. T

ACKNOWLEDGMENTS

The authors would like to thank the following individuals and organizations for their assistance in obtaining the data necessary to complete this project. Geologic material strength data were collected at: 1) the Los Angeles County Department of Public Works with the assistance of Robert Larsen, James Shuttleworth, Charles Nestle, and Dave Poplar, 2) the City of Los Angeles with the assistance of Nicky Girmay, and 3) the City of Glendale with the assistance of Kurt Erickson, Bruce Thompson, and William A'Hearn. Digital terrain data were provided by Randy Jibson of the U.S. Geological Survey (USGS DEM), Scott Hensley of JPL, and Gerald Dildine and Chris Bohain of Calgis, Inc. (Radar DEM). Technical review of the methodology was provided by Bruce Clark, Randy Jibson, Robert Larson, Scott Lindvall, and J. David Rogers, who are members of the State Mining and Geology Board's Seismic Hazards Mapping Act Advisory Committee Landslides Working Group. At DMG, special thanks to Bob Moskovitz, Teri McGuire, Barbara Wanish, and Scott Shepherd for their GIS operations support, and to Barbara Wanish for preparing the graphic displays associated with the Hazard Zone Map and this report.

REFERENCES

Barrows, A. G. and Irvine, P.J., 1991, Field investigations of Sierra Madre earthquake, June 28, 1991: California Department of Conservation, Division of Mines and Geology internal memo to Michael Reichle, Geohazards Supervisor, 2 p.

Brabb, E.E., 1983, Map showing direction and amount of bedding dip of sedimentary rocks in San Mateo County, California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1257C, 1 sheet, scale 1:62,500.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

California State Mining and Geology Board, in press, Criteria for delineating seismic hazard zones: California Department of Conservation, Division of Mines and Geology, Special Publication 118, 21 p.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, pp. 1645-1649.

Crook, R. Jr., Allen, C.R., Kamb, B., Payne, C.M.,and Proctor, R.J., 1987, Quaternary Geology and seismic hazard of the Sierra Madre and associated faults, western San Gabriel Mountains, *in* Recent reverse faulting in the Transverse Ranges, California: U.S. Geological Survey Professional Paper 1339, p. 7 –26.

Dibblee, T.W., Jr., 1989, Geologic map of the Pasadena quadrangle, Los Angeles County, California: Dibblee Geological Foundation Map DF-23, Santa Barbara, California, scale 1:24,000.

GeoSAR Consortium, 1995, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B335/00, 135 p.

GeoSAR Consortium, 1996, Year 1: Research and development status report for GeoSAR, a radar-based terrain mapping project: U.S. Government's Advanced Research Projects Agency Contract Order No. B378/00, 70 p.

Harp, E.L. and Jibson, R.W., 1995, Inventory of landslides triggered by the 1994 Northridge, California earthquake: U.S. Geological Survey Open-File Report 95-213, 17 p., Plate 1 scale 1:100,00; Plate 2 scale 1:50,000.

Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.

Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.

Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.

Lamar, D.L., 1970, Geology of the Elysian Park- Repetto Hills area, Los Angeles County, California: California Division of Mines and Geology Special Report 101, 45 p.

McCalpin, J.P., unpublished, Digital geologic map of the Pasadena 7.5-minute Quadrangle, California: contracted for the Southern California Areal Mapping Project (SCAMP), compilation scale 1:24000.

McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.

Morton, D. M. and Kennedy, M.P., 1989, A southern California digital 1:100,000-scale geologic map series: The Santa Ana Quadrangle, The first release: Geological Society of America Abstracts with Programs v. 21, no. 6, p. A107-A108.

Morton, D.M. and Streitz, Robert, 1969, Preliminary reconnaissance map of major landslides, San Gabriel Mountains, California: Division of Mines and Geology Map Sheet 15, scale 1:62,500.

Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: Geotechnique, v. 15, no. 2, p. 139-160.

Petersen, M.D., Cramer, C.H., Bryant, W.A., Reichle, M.S. and Toppozada, T.R., 1996, Preliminary seismic hazard assessment for Los Angeles, Ventura, and Orange counties, California, affected by the January 17, 1994 Northridge earthquake: Bulletin of the Seismological Society of America, v. 86, no. 1B, p. S247-S261.

Smith, D. P., 1986, Geology of the north half of the Pasadena quadrangle, Los Angeles County, California: Division of Mines and Geology Open File Report 86-4 LA, 40 p.

Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

Treiman, J.A., unpublished, Landslide inventory of the Pasadena 7.5' Quadrangle, Los Angeles County, California.

Trifunac, M.D., Todorovska, M.I. and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: Soil Dynamic and Earthquake Engineering, v. 13, no. 3, p. 187-196.

USGS (U.S. Geological Survey), 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

USDA (U.S. Department of Agriculture), 1952/53, Aerial photography, Flight AXJ, Frames 6K 78-85, 7K 28-36, 92-101, 14K 7-13, 15K 121-126, 166-168, 16K 1-5, black and white, vertical, scale 1:20,000.

USGS (U.S. Geological Survey), 1994a, NAPP Aerial Photography, Flight 6858, May 31, 1994, Frames 59-62 and 91-93, black and white, vertical; scale 1:40,000.

USGS (U.S. Geological Survey), 1994b, NAPP Aerial Photography, Flight 6864, May 31, 1994, Frames 220 and 221, black and white, vertical; scale 1:40,000.

APPENDIX A
SOURCES OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
City of Glendale, Public Works Division	**42**
Los Angeles County Public Works Department	**59**
Geotechnical reports from environmental impact documents and DMG staff on file at DMG	**8**
City of Los Angeles, Department of Public Works	**133**

Total number of tests used to characterize the units in the Pasadena Quadrangle.	**242**

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Pasadena 7.5-Minute Quadrangle, Los Angeles County, California

By

Mark D. Petersen, Chris H. Cramer, Geoffrey A. Faneros, Charles R. Real and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation, Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (1997; also available on the Internet at http://www.consrv.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included, are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5- minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (California State Mining and Geology Board, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2, addressing liquefaction and earthquake-induced landslide hazards, constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet homepage: http://www.consrv.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the seismogenic sources as published in the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

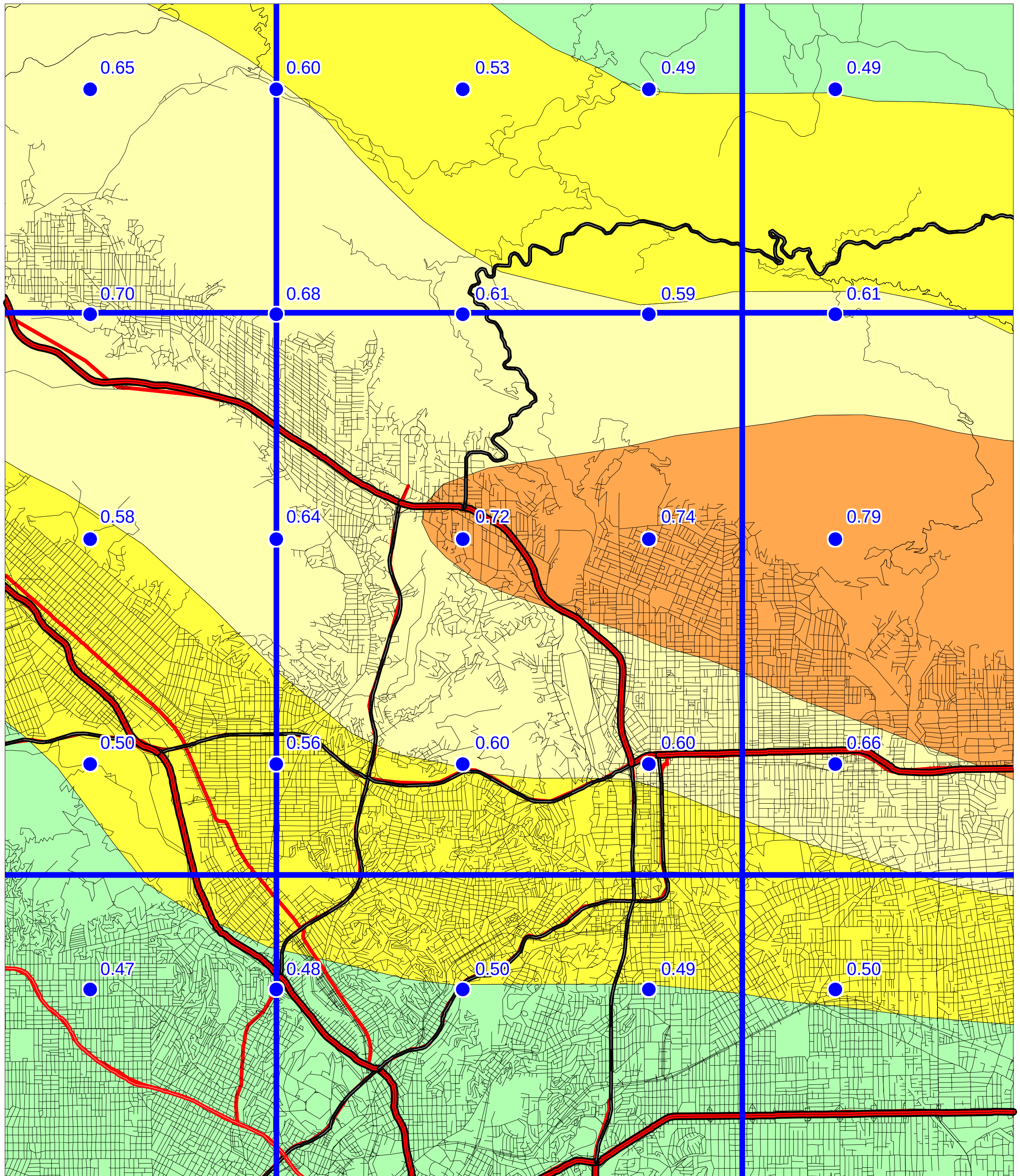
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

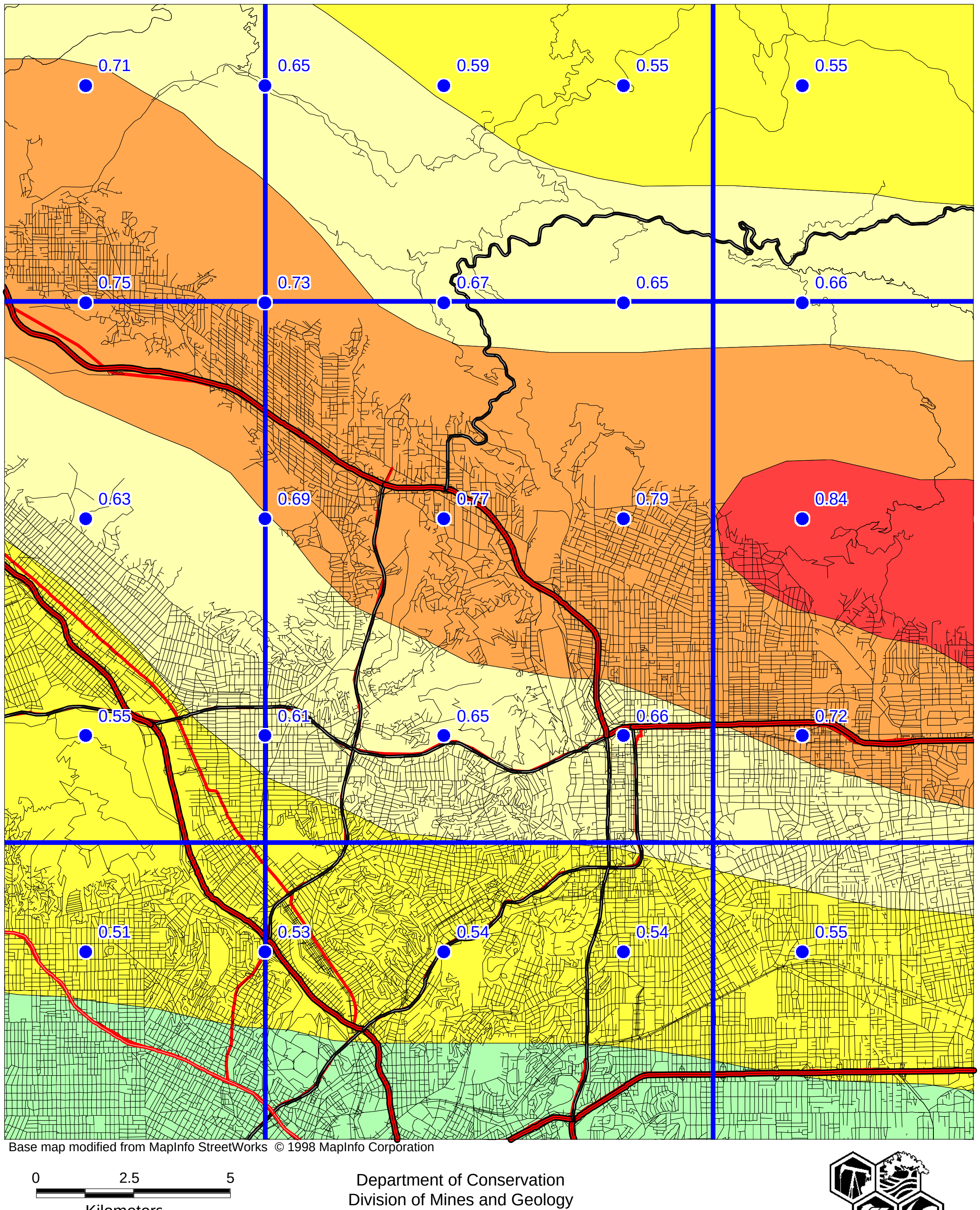
Figure 3.1

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Department of Conservation
Division of Mines and Geology

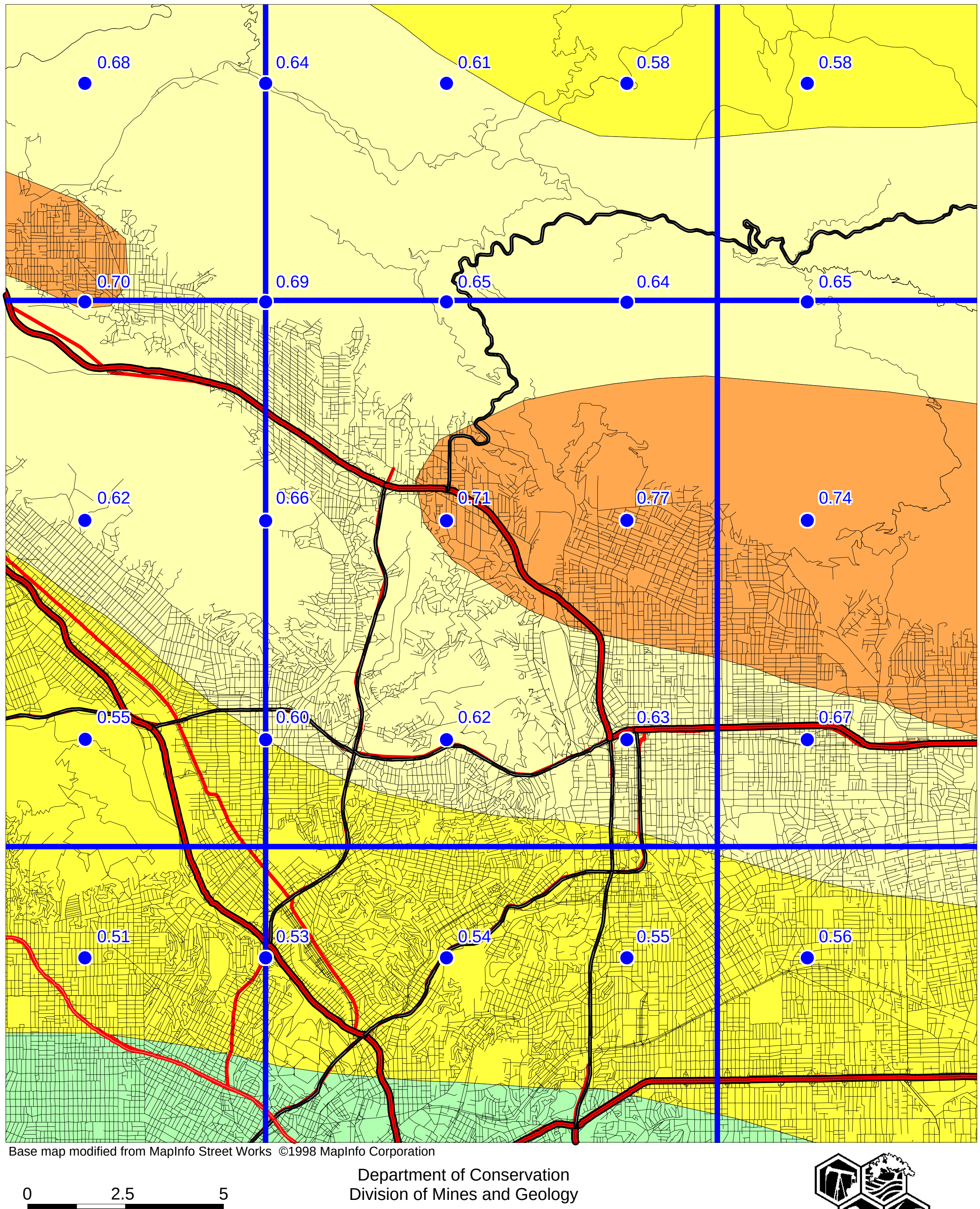
Figure 3.2

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Department of Conservation
Division of Mines and Geology

Figure 3.3

values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

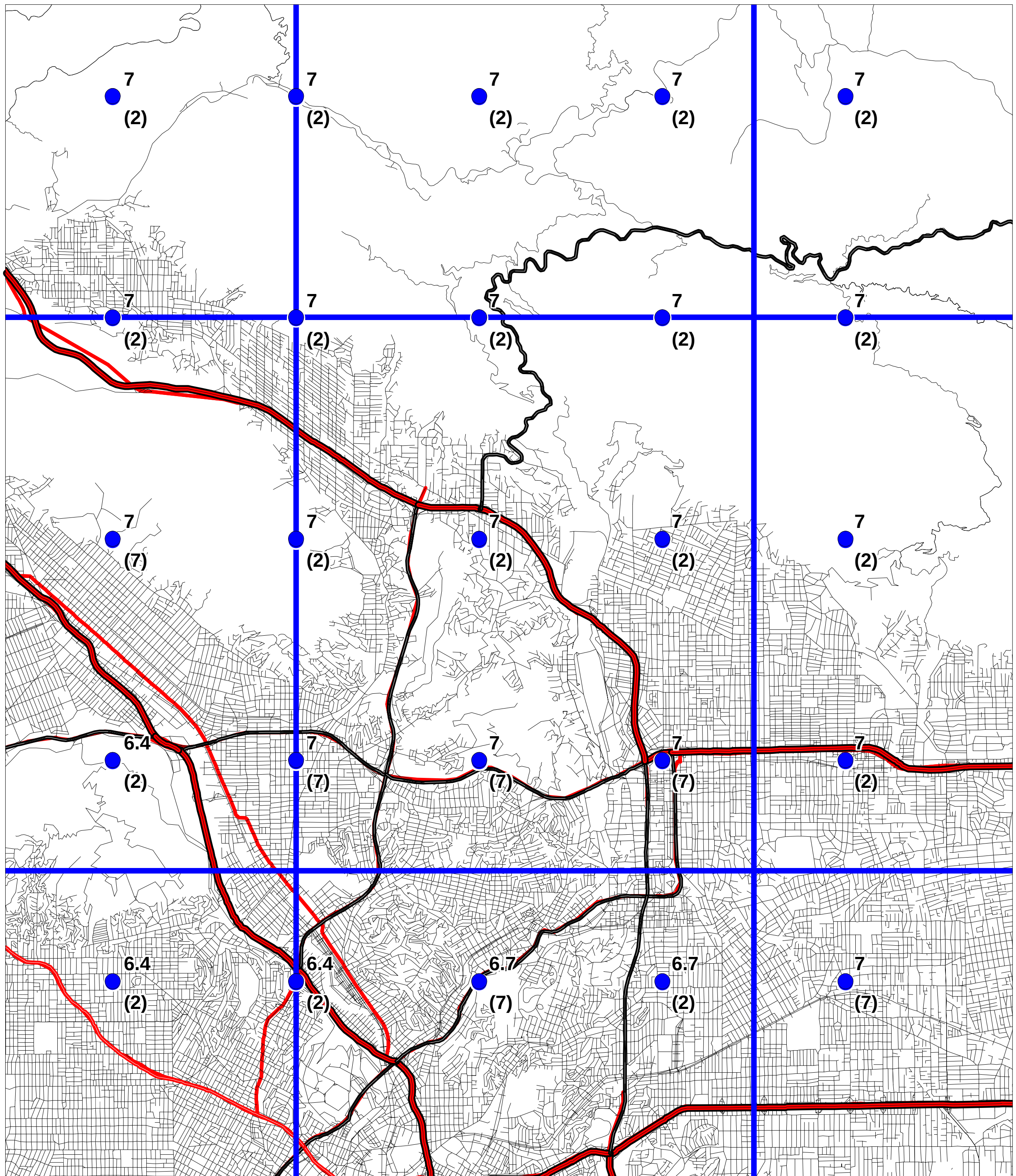
1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

PASADENA 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE
Magnitude (Mw)
(Distance (km))



Base map modified from MapInfo StreetWorks ©1998 MapInfo Corporation

0 2.5 5
Kilometers

Department of Conservation
Division of Mines and Geology

Figure 3.4

have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not previously been recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (California State Mining and Geology Board, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, p. 154-179.

California State Mining and Geology Board, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Department of Conservation, Division of Mines and Geology, Special Publication 117, 74 p.

Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, p. 180-189.

Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: Bulletin of the Seismological Society of America, v. 85, no. 5, p. 1645-1649.

Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: Bulletin of the Seismological Society of America, v. 86, p. 1681-1691.

International Conference of Building Officials (ICBO), 1997, Uniform Building Code: v. 2, Structural engineering and installation standards, 492 p.

Jennings, C.W., *compiler*, 1994, Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.

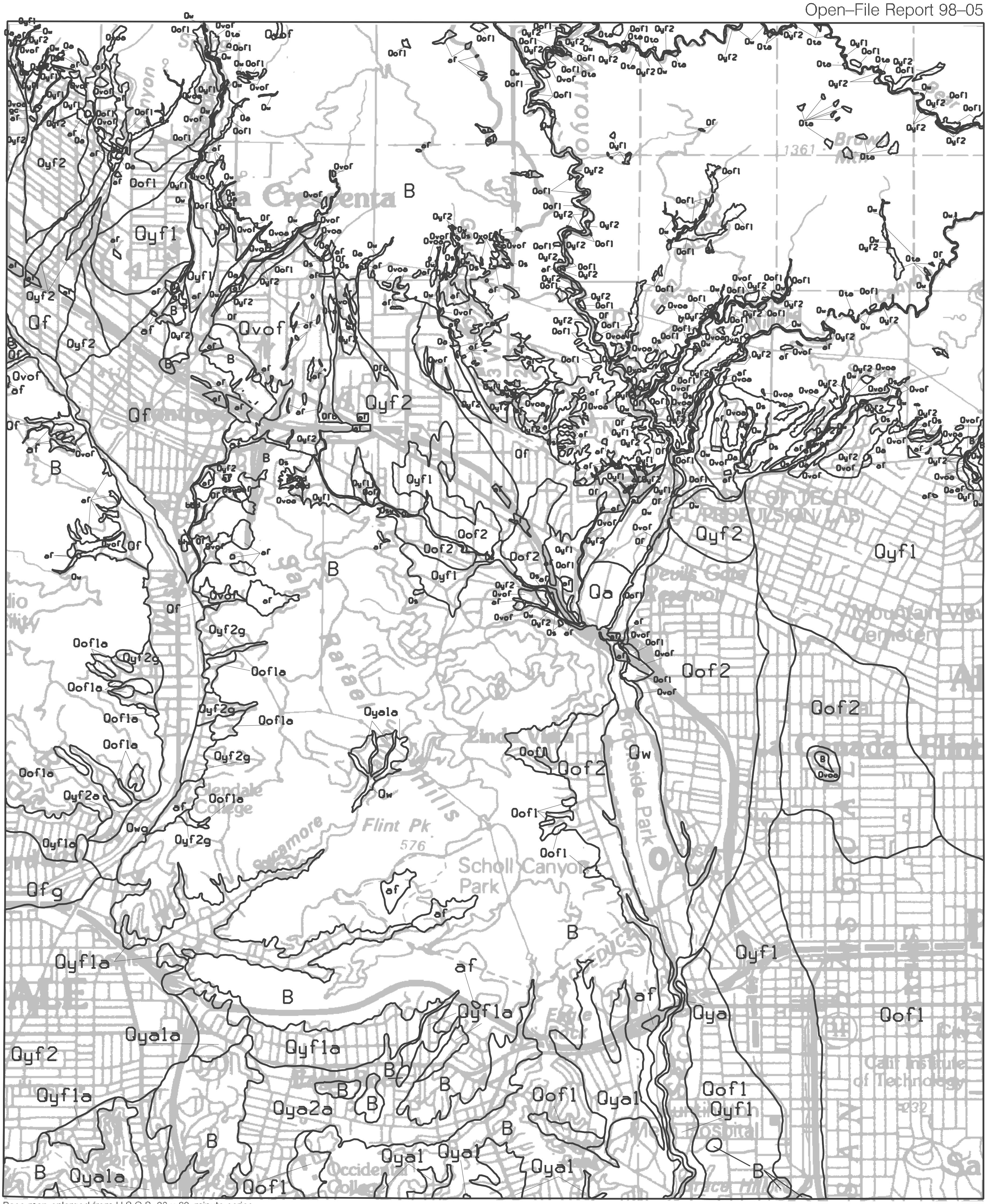
Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 66 p.

Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.

Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.

Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.

Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.



Base map enlarged from U.S.G.S. 30 x 60–minute series

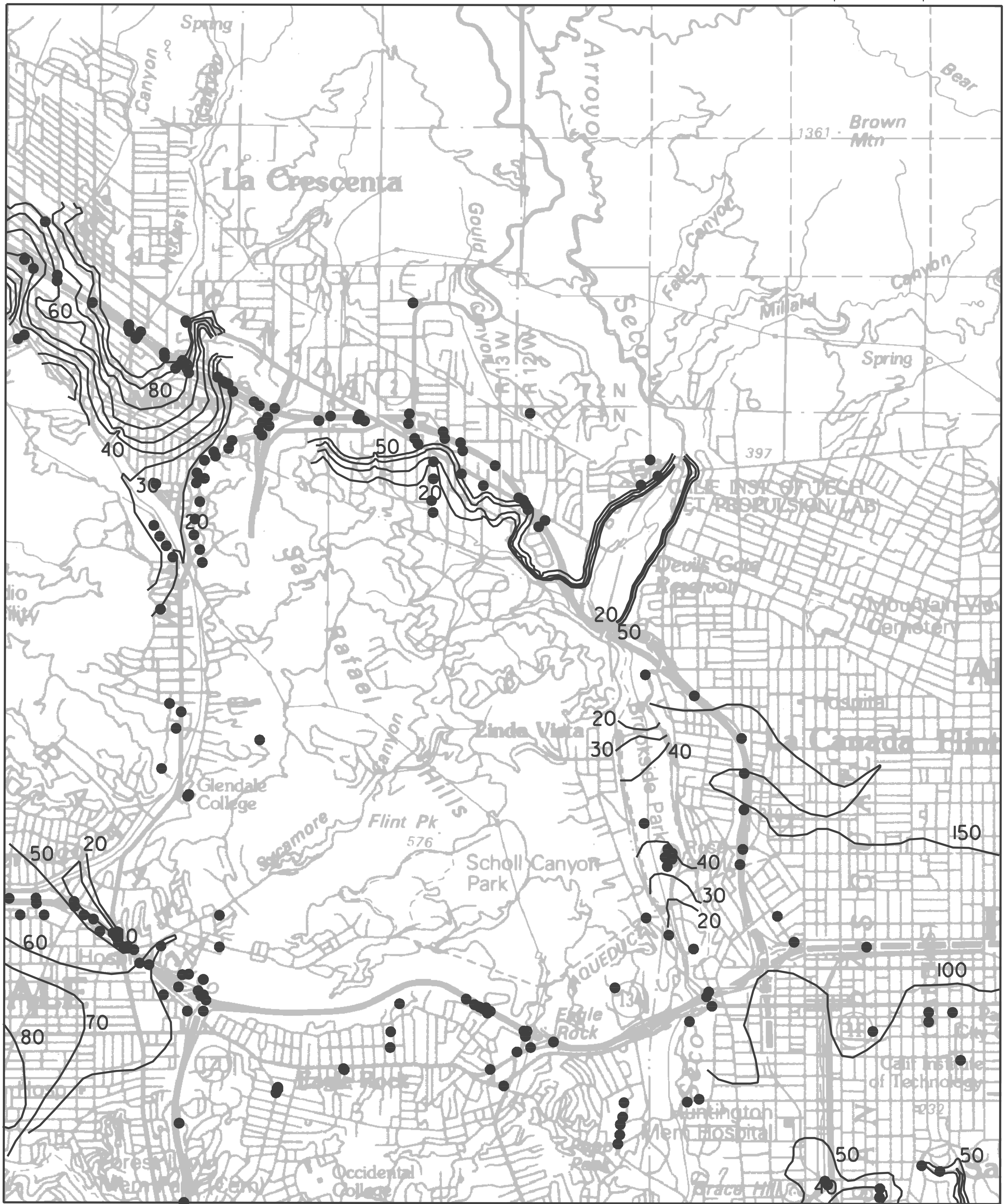
Plate 1.1 Quaternary Geologic Map of the Pasadena Quadrangle.

See Geologic Conditions section in report for descriptions of the units.

B = Pre–Quaternary bedrock.

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

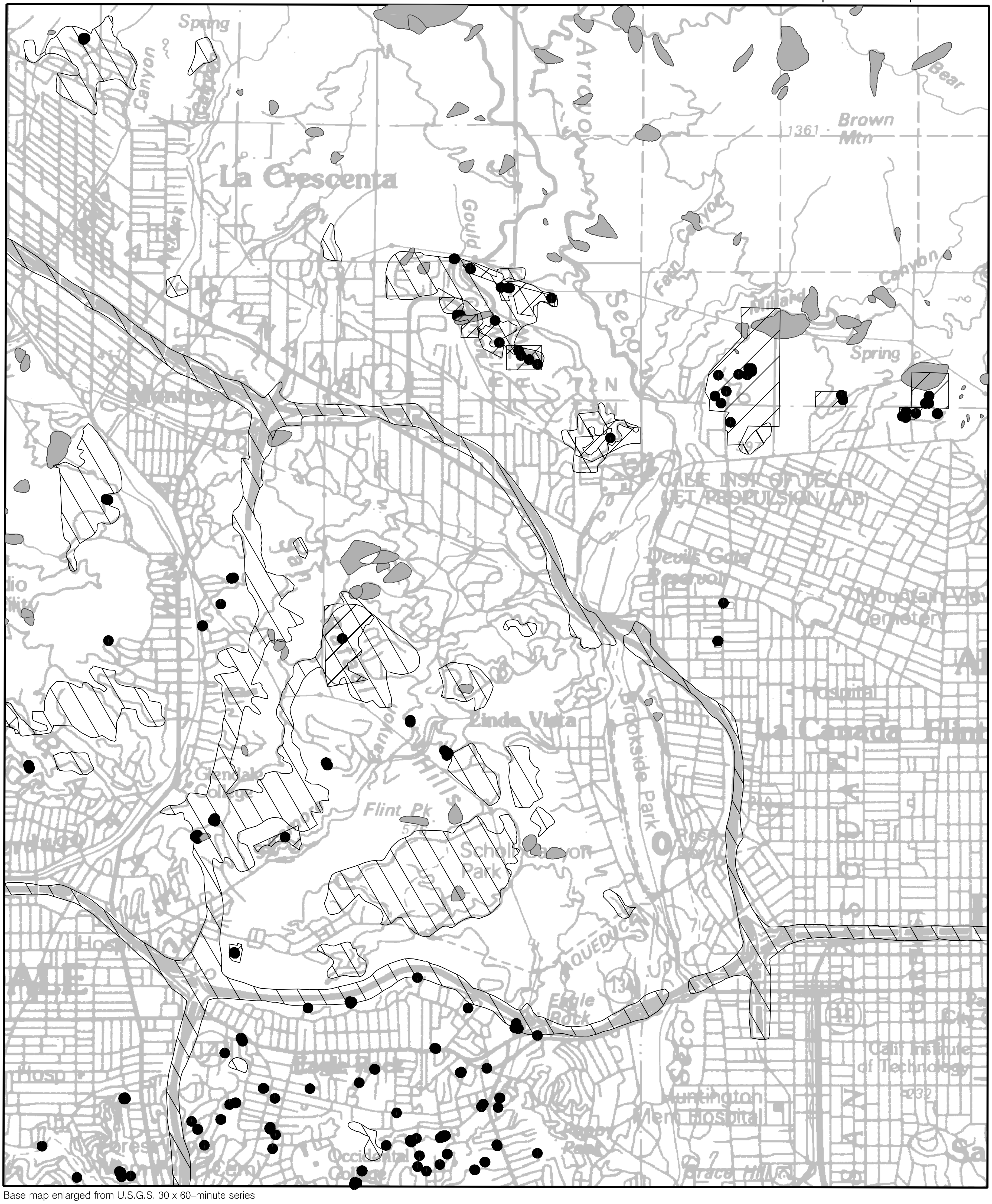
Plate 1.2 Historically Highest Ground Water Contours and Borehole Log Data Locations, Pasadena Quadrangle.

● Borehole Site

30 Depth to ground water in feet

ONE MILE

SCALE



Base map enlarged from U.S.G.S. 30 x 60–minute series

Plate 2.1 Landslide inventory, data collection site and tract location map, Pasadena Quadrangle.

Boring or sample location   Landslide   Areas of significant grading   Tract report with multiple borings

ONE MILE

SCALE